A REACTANCE TUBE CONTROLLED OSCILLATOR OF UNUSUALLY WIDE FREQUENCY SWEEP

By B. M. BANERJEE
INSTITUTE OF NUCLEAR PHYSICS, 92, UPPER CIRCULAR ROAD, CALCUTTA-9

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ABSTRACT. A reactance ube oscillator producing an unusually wide frequency sweep has been described.

INTRODUCTION

Reactance tube controlled oscillators are utilized in the automatic frequency control systems of superheterodyne receivers and in reactance tube modulators of simple types of frequency modulation transmitters. A wide range of frequency sweep is advantageous in both applications. Commonly, however, this sweep is of the order of a few tens or hundreds of kilocycles. The need for a wider range of sweep was actually felt in connection with the development of automatic frequency control systems of the receiver of an ionospheric sounding equipment (Banerjee and Roy, 1952). Reactance tube oscillators of conventional design (Reich, Young and Beck, 1949, Hund and others) could not provide a sweep greater than a megacycle. In the modified design described here, sweeps as great as 16 megacycles were obtained.

A reactance tube oscillator may be broken up functionally into the parts shown in the block diagrams given below (figure 1).

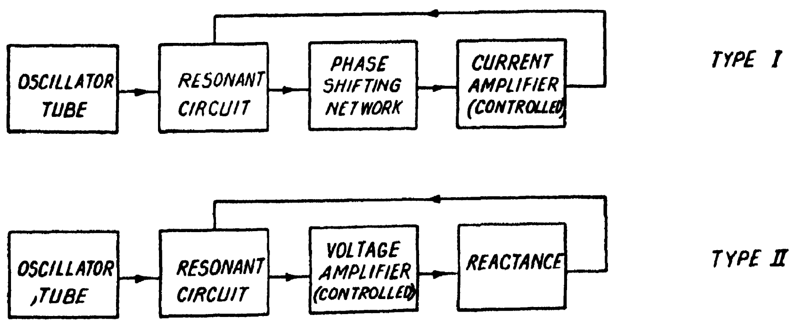

FIG. 1 Block diagram of reactance tube oscillator.

Type I alone is suitable for producing a wide frequency sweep in high frequency oscillators. The difficulty in obtaining amplification with a phase shift close to zero or 180 degrees limits application of type II mainly to the audio-frequency region.

To produce a frequency change in an oscillator, the reactive elements of the frequency controlling resonant circuit is varied. As the frequency of oscillation is given by the expression,

$$f = \frac{1}{2\pi\sqrt{LC}}$$

the change in frequency is given by

$$\Delta f = -\frac{f}{2} \cdot \frac{\Delta C}{C} = -\frac{f}{2}\left(\frac{\Delta X_c}{X_c}\right).$$

Now X_c may be written as

$$X_c = E/I_c$$

where

E = voltage across the capacity

and I_c = charging current through this capacity, so that

$$\left|\frac{\Delta f}{f}\right| = \frac{1}{2}\frac{\Delta I_c}{I_c}$$

where ΔI_c is the reactive current taken by the reactance tube, which thus behaves as a reactance element and produces the frequency change Δf, and I_c is the charging current through the actual reactance.

The current ΔI_c through the reactance tube is limited to a peak value nearly equal to the *d. c.* anode current passed by this tube. This cannot be increased indefinitely. To obtain a large value of $\frac{\Delta f}{f}$, one has to arrange circuit conditions such that the maximum r. f. current through the reactance tube is obtained for a minimum charging current in the actual reactance. This is accomplished by reducing the unavoidable capacitances in the resonant circuit to a minimum value, so that the charging current of the actual reactance has the minimum value for a given resonant circuit voltage. A further reduction of the charging current is possible, if the resonant circuit r. f. voltage is reduced, while a full modulation of the reactance tube current is retained, so that ΔI_c has the maximum value obtainable. In the conventional arrangement, the phase shifting network introduces an amplitude reduction of three to ten times (Reich), so that even if a high transconductance tube is utilized in the current amplifier position, a fairly large r. f. voltage must remain on the resonant circuit to secure full modulation of its current. In the arrangement described here (figures 2 and 3), an amplifier is interposed between the resonant circuit and the current amplifier, in such a manner that its associated coupling elements naturally secure the necessary 90° phase shift, while giving an amplification of the resonant circuit voltage. A great reduction of the resonant circuit operating voltage is thus permissible, with a corresponding increase in the frequency sweep.

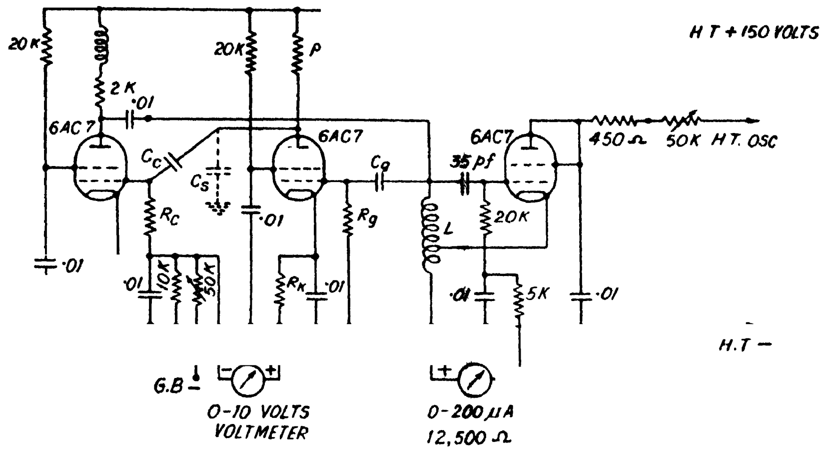

FIG. 2 Improved reactance tube oscillator utilizing 6AC7 tubes. Suitable for frequencies below 30 Mc/s.

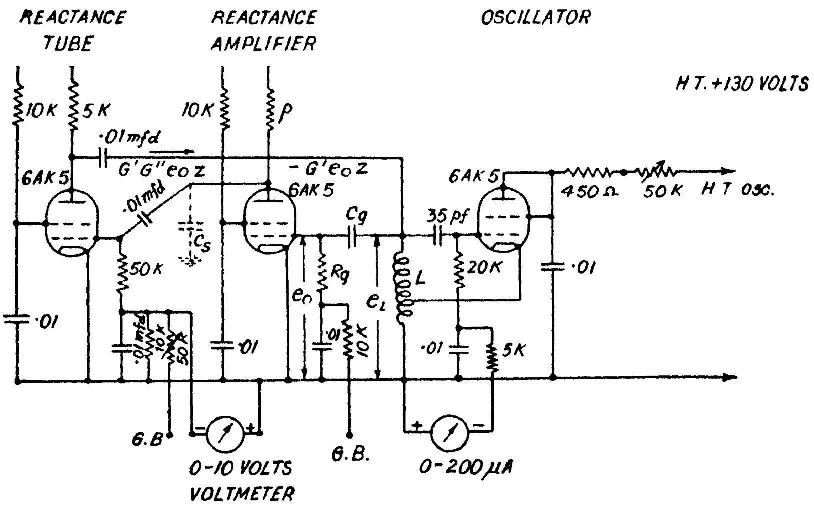

FIG. 3 Improved reactance tube oscillator utilizing 6AK5 tubes. Suitable for operation above 30 Mc/s.

THE CIRCUIT

The circuits developed have the forms shown in the figures 2 and 3. They consist of an oscillator, a reactance amplifier and the reactance tube. Radio-frequency oscillations, generated by the Hartley type oscillator circuit, are developed across the resonant circuit inductance L, which has as the tuning capacity, the input capacities of the oscillator and reactance amplifier and the output capacity of the reactance tube, besides the component and wiring capacities to ground. The oscillator anode voltage, controlled by the 50K adjustable resistance, sets the amplitude of the r. f. oscillations to the optimum value. The r. f. oscillation across L is applied through a C_gR_g coupling network to the grid of the reactance amplifier. The reactance amplifier is a resistance coupled wide-band amplifier. The amplified voltage is applied to the grid of the reactance tube through another $C_g R_g$ network. The output current of the reactance tube is made to pass through the oscillator resonant circuit, and is controlled as usual by varying the grid bias. The 90° phase shift needed between the output current of the reactance tube and the voltage across the resonant circuit, is obtained automatically, when the component values of the $C_g R_g$ coupling networks and $C_s\rho$ network of the reactance amplifier are suitably proportioned. In that condition, the frequency of oscillations generated by the arrangement changes over a range of several megacycles as the grid bias of the reactance tube is varied while the amplitude of the oscillations remain sensibly constant. This is indicated by the oscillator grid current meter. When the component values are such that the phase shift deviates considerably from 90°, the in-phase or out-of-phase component of the reactance tube current produces a powerful degenerative or regenerative action. As a result, as the grid bias of the reactance tube is diminished, so as to allow greater current flow through the reactance tube, the oscillator grid current decreases, leading ultimately to cessation of oscillations or increases leading ultimately to squegging. When the values of these components, the value of ρ particularly, are adjusted to optimum, the frequency sweep obtained is a maximum, squegging is removed and there is a small variation of the oscillator grid current with reactance tube grid bias.

When the operating frequency is below 30 Mc/s, the gain available from the reactance amplifier is substantial. The large gain in the feedback loop then makes it impossible to avoid squegging even with critical adjustments* of the value of ρ.

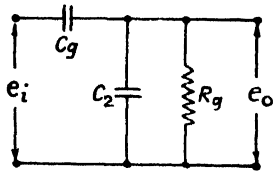

FIG. 4

e_i = Voltage at input of $C_g R_g$ network.
e_o = Voltage at output of $C_g R_g$ network.
C_g = Coupling capacity, e.g., capacity between resonant circuit to reactance amplifier grid.
i_c = Current through C_g when the output terminals, i.e., e_o is short-circuited in figure 4.
$= e_i/\omega C_g$.

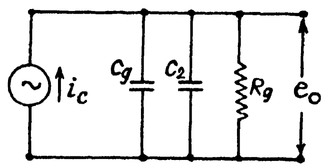

FIG. 5

C_2 = Shunting capacity to ground at the output terminals of the $C_g R_g$ network, e.g., reactance amplifier input capacity.
R_g = Resistive component across the output terminals, e.g., grid leak of the reactance amplifier; at high frequencies, input resistance of the reactance amplifier grid circuit —that due to transit time effects.

* It will be appreciated from the phase diagrams that are given later, that there will be me movement in the output current phase when the frequency sweep is a good fraction the operating frequency.

It is then judicious to throw off some loop gain by reducing the coupling capacity between the resonant circuit and the reactance amplifier.

The phase diagrams are given in the figures 4, 5 and 6. In figures 4, 5 and 6 the phase shift ϵ between the input and output voltages of a $C_g R_g$ coupling network is calculated. It is positive—the output phase leads the input. The system is conveniently analysed by application of Norton's theorem.* i_c is the current through C_g when the output terminals are short-circuited. The resultant output voltage is, therefore, equal to the voltage developed due to i_c flowing through the parallel combination of C_g, C_2 and R_g.

In figure 3, Z represents the impedance of the parallel combination of ρ and C_s, the reactance amplifier anode load and shunting capacity. This has an amplitude

$$|Z| = \frac{\rho}{\sqrt{1 + \omega^2 C_s^2 \rho^2}}$$

and phase θ given by

$$\tan \theta = -\omega C_s \rho$$

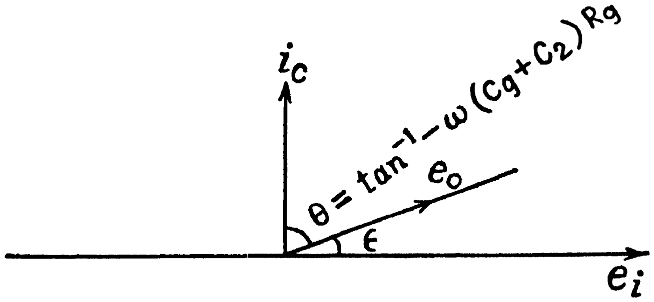

FIG. 6. Phase diagram of a $C_g R_g$ coupling network.

The resultant phase diagram of the circuit, therefore, is of the nature given in figure 7. ϕ_1 and ϕ_2 represent the angles due to transit time delays in the reactance amplifier and reactance tubes. With 6AC7 tubes, ϕ_1 and ϕ_2 are not negligible at 30 Mc/s.

PERFORMANCE

The performance of several typical circuit combinations are presented in the curves of figures 8, 9, 10, and 11. They were obtained with two different circuit arrangements, figures 2 and 3, one utilizing 6AC7 tubes and the other 6AK5. Transit time effects make it desirable to utilize the 6AK5 circuit above 30 Mc/s. Compared to the conventional reactance tube circuits, oscillation is secured more readily in this new type of circuit. The phase-shifting R-C combination in the conventional reactance tube circuit introduces a large damping on the oscillator resonant circuit. This is avoided in the newly developed circuit. When the operating frequency is high ($>$ 30 Mc/s), this factor assumes considerable importance.

* Everitt—Communication Engineering—p. 48.

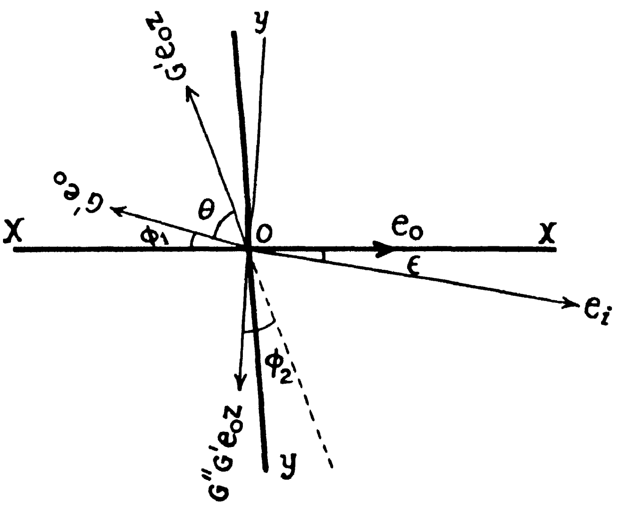

FIG. 7

Phase diagram of the reactance tube current. Resultant phase difference between output current and resonant circuit voltage $= \epsilon + (180 - \phi_1 - \theta) + (180^\circ - \phi_2) = 360^\circ - (\theta + \phi_1 + \phi_2 - \epsilon)$.

ϵ = Phase shift between the input and output voltages of a $C_g R_g$ network.

ϕ_1, ϕ_2 = Phase lag due to transit time delays in the reactance amplifier and reactance tube. θ = Phase lag between the output current and voltage $G'e_0Z$ of the reactance amplifier. $(\theta+\phi_1+\phi_2-\epsilon)$ should be close to 90° : degenerative when greater than 90° and regenerative when less than 90° ; degenerative when ρ is greater than optimum and regenerative when ρ is less than optimum.

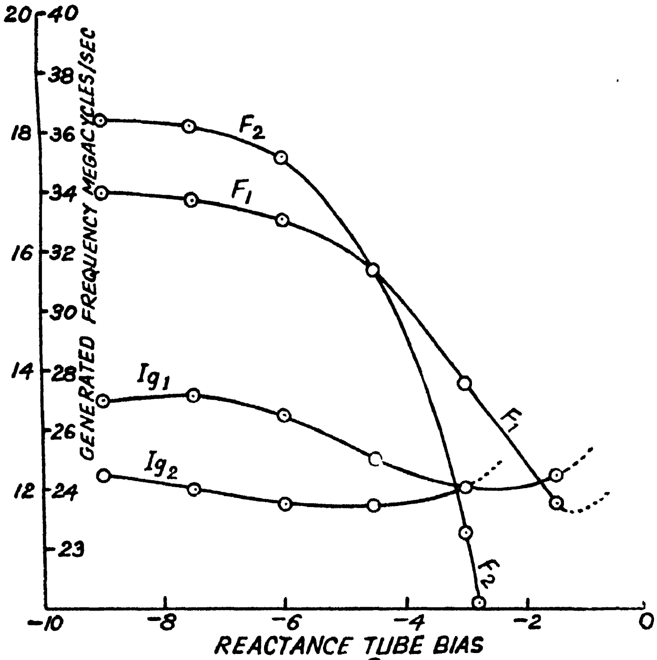

FIG. 8.

Characteristics of a wide sweep reactance tube oscillator utilizing circuit of figure 2. The curves marked F give the variation of frequency with reactance tube grid bias voltage, while curves marked I_g show the variation of oscillator grid current with reactance tube grid bias. Curves with suffix 1 were obtained with $\rho=500$ ohms : $R_c=50$ K; $R_g=2$K; $C_c=.01$ mfd; $C_g=11$ pf., curves with suffix 2 with $\rho=500$ ohms: $R_c=R_g=50$ K; $C_c=C_g$ $=11$ pf; the resonant circuit had a measured stray capacity of 32 pf across it. Suffix 1 corresponds to the frequency range 20-40 Mc/s; Suffix 2 for 10-20 Mc/s. The minimum frequency reached in the first arrangement is 21.3 Mc/s. It was obtained when the oscillator H. T. was reduced to 14 volts from the normal value of 40 volts Reduction of reactance tube bias beyond -2.8 volts in arrangement 2 caused squegging. Frequencies were measured with calibrated receivers. (Hammarlund BC 779: Hallicrafter S-27).

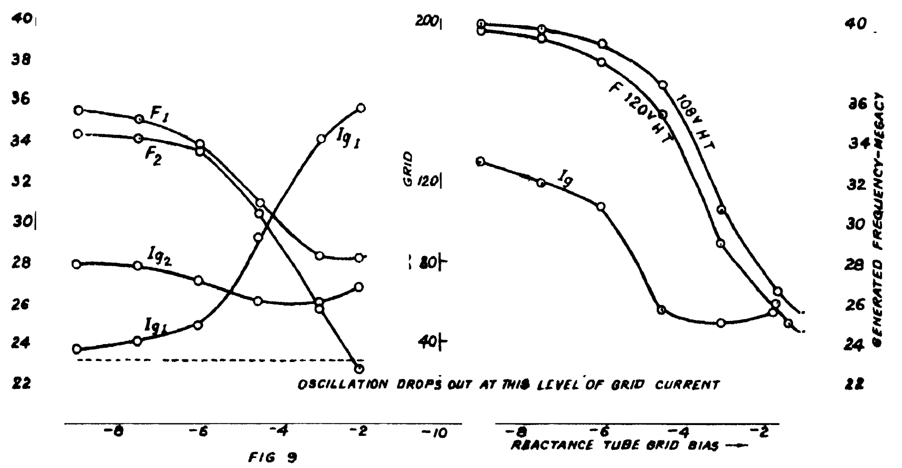

FIG 9

Characteristics of a reactance tube oscillator utilizing circuit of figure 3. Curves with suffix 1 utilized $\rho=1000$ ohms, $R_c=R_g=50$ K; $C_c=.01$ mfd: $C_g=7.5$ pf; Osc. H. T. +24 volts; Reactance amplifier bias $-1\ 5$ volts; oscillation frequency=36 Mc/s with no H T. on reactance amplifier and reactance tube; squegging completely removed. Curves with suffix 2 utilized $\rho=3000$ ohms; $C_c=C_g-15$ pf; $R_c=R_g=50$ K; Osc. H. T. +24 volts; R. A. bias -1.5 volts; R.A. and R. T. anode supply reduced to 108 volts to avoid squegging. Minimum frequency of 21.8 Mc/s reached when oscillator H. T. is reduced to zero. Maximum frequency of 34.6 mc's is obtained when R. A. and R. T. H. T. is zero.

Characteristics of reactance tube oscillator utilizing circuit of figure 3. $\rho=3000$ ohms; $C_c=C_g=15$ pf. $R_c=R_g=50$ K; Osc. H. T. +24 volts; R. A. bias $-1\ 5$ volts; oscillation frequency=40 Mc/s with no H T. on R. A. and R. T. Minimum oscillation frequency of 23.7 Mc/s reached when oscillator H. T. was reduced to zero

When the frequency sweep required is a good fraction of the operating frequency, the arrangement becomes very susceptible to squegging, at certain values of the reactance tube bias. To minimize this tendency to generate interrupted oscillations, it is not enough to reduce the grid condenser and grid leak values. It is also desirable to have a separate low-internal resistance source for the oscillator high tension.

It is to be noted that as the grid bias is reduced, the generated frequency diminishes up to a certain limit, beyond which it again tends to increase.

It must not be forgotten that wide frequency sweep is obtained at the cost of the amplitude of generated oscillations. In applications, where amplitude of the generated oscillations (R.F.) is important, a suitable compromise must be made in the actual design. Wide-band amplifiers are to be incorporated, in case where such compromise would not satisfy requirements.

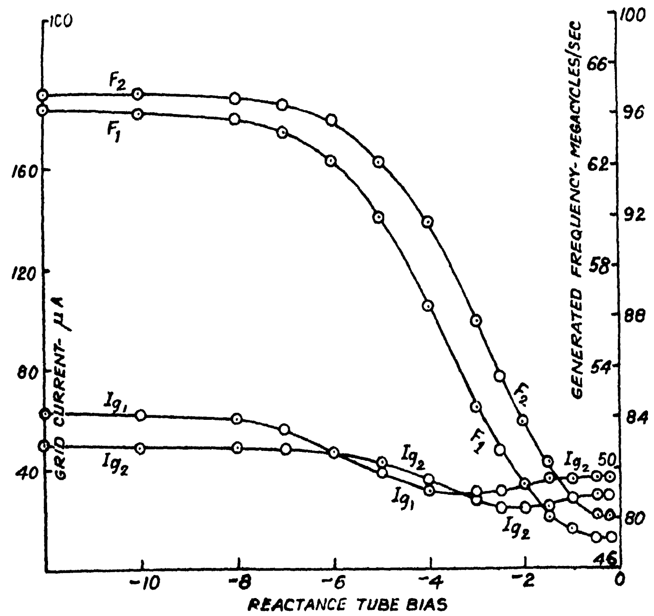

FIG. 11. Characteristics of reactance tube oscillators utilizing circuit of figure 3. Curves with suffix 1 utilized a centre tapped 5 turn coil of 1/2 inch diameter (frequency scale 46-66 mc/s); $\rho=1{,}000$ ohms; $R_c=R_g=50$ K Ω. $C_c=C_g=15$ pf; oscillator H. T. +36 volts; reactance amplifier grid bias $=-1.5$ volts; maximum frequency of 64.9 Mc/s reached when R. A. and R. T. H. T. is zero; no squegging.

Curves with suffix 2. utilized a 5 turn centre tapped coil of 1/4 inch diameter; frequency scale 80-100 Mc/s; $\rho=310$ ohms; $R_c=R_g=50$ K Ω, $C_c=C_g=15$ pf.; oscillator H. T. +30 volts; Reactance amplifier bias $=-0\ 5$ volts; maximum frequency=98.3 Mc/s reached when oscillator H. T. is reduced; no squegging.

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